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(Selected Articles)

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CHINA'S AERONAUTICAL FORGINGS AND CASTINGS REVIEWED

Liu Duopo[1], Zeng Fanchang[2], and Xue Yanlu[3]
China Aeronautical Forgings and Castings Technology Import and Export Association

At an Aeronautical Forgings and Castings Trade Fair sponsored by the Aeronautical Forgings and Castings Technology Import and Export Association (of the China National Aeronautical Technology Import and Export Corporation), more than 700 items of Chinese-made goods were exhibited, including aeronautical forgings, castings, forging dies, casting molds, powder metallurgical products, and titanium alloys and products. These goods symbolize China's production capability and technical level of aeronautical forgings and castings, with excellent qualities of these products.

Production Capability of Aeronautical Forgings and Castings

With the establishment, development and growth of China's aviation industry, metallurgy industry, machinery manufacture industry, and professional research organizations, China has acquired the production capabilities of high-quality forgings and castings for various models of military and civil aircraft, engines

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and accessories. As early as the mid-1960s, China was able to produce various metal materials and large forgings required by aviation industry.

At present, all aeronautical castings have been produced by China's aviation industrial departments. Only about 10 percent of the forging items (large ferrous and non-ferrous forgings) are supplied by the metallurgy and civilian machinery industrial departments; the other 90 percent of forgings are produced by aviation industrial departments.

Regarding the production facilities of aeronautical forgings in China, major facilities include 10- and 16-ton die forging hammers, 25 ton·meter hammer-to-hammer-striking (without an anvil) machines, 40 ton·meter gunpowder-powered hammers, 100 ton·meter high-speed hammers, 12,000-ton free forging hydraulic presses, as well as 10,000- and 30,000-ton die forging hydraulic presses. Those small- and medium-sized forgings (as well as blades) are manufactured with 6.5 to 30 ton·meter high-speed-hammer forging machines, 1600- to 4000-ton hot die-forging mechanical presses, 160- to 1000-ton friction presses, as well as 5-ton (and less) die forging hammers and free forging hammers. Those hydraulic screw hammer presses (imported from abroad recently) will be used in precision forgings of blades and complex-configuration parts. In production of ring-shaped goods, broaches are used in whole-piece rolling of various types (700 to 1500 mm in diameter) of ring-shaped parts; this is an economical and practical technique.

Regarding aeronautical casting production, the aviation industrial departments have the following facilities: forming, smelting, pouring and cleaning of sand casting, metal die casting, melting-mold precision casting, pressure casting, and centrifugal casting. With these facilities, ordinary and precision castings of complex shapes can be produced. The hollow turbine blades, hollow guiding blades (made with ceramic-core precision casting technique), and other turbine blades (made with the directional condensation technique) will be successfully assembled in advanced aircraft engines.

Moreover, the aviation industrial departments can produce high-purity high-characteristics mother alloys while making high-temperature alloy castings.

Diagrams on the back cover show Chinese-made aircraft and the typical forgings and castings in an aircraft engine.

China's aviation industry has a very high production capacity in making forgings and castings. Besides meeting domestic demands, the industry exports forgings and castings of different usages. Chinese aeronautical forgings have begun to be exported by the aviation industry. China's aviation forging and casting plants (and shops) have fully-equipped, modern inspection equipment and quality control laboratories. In the various manufacturing steps of forging and casting products, from raw material to forging, casting and heat treatment, strict quality control is conducted. The Beijing Aeronautical Material Institute is a research center studying new materials, heat treatment technique, and quality control of China's aviation industry.

Technical Level of Aeronautical Forgings

The important criteria in evaluating the technical level of forgings are such geometrical factors as dimensions, shapes and precision, as well as material utilization rate and metallurgy quality.

At present, the forging press engineering circles, both domestic and abroad, are exerting their efforts in developing large integrated and precision forgings. Integration leads to an improvement of structural design of the aircraft and its engine; this is an important means to raise structural strength, reduce structural weight, and exploit material potential. In modern high-speed aircraft and aero-engines, more and more large integral structural members are used in place of the past method of assembling several parts into one structural member. Precision forging can reduce the excess amount for machining to a minimum so that the forging shapes are as close to the finished products as possible; precision in forgings can be achieved by improving technique and design. At present, in China generally the material utilization rate of large aviation forgings is approximately 10 to 25 percent. Abroad, large investment was laid out to develop heavy forging presses in order to carry out integration and precision techniques. Proceeding toward this target, China's aviation industry does not solely seek larger tonnage in forging presses; the Chinese stress to seek the best technique and design of forgings to rationally specify the process of deformation technique and apply such technical measures as are helpful to reduce metal deformation resistance and stress in order to produce larger and more precise aeronautical forgings.

The partitioned integral forging members in an aircraft are die forged with a 30,000-ton hydraulic press. For a large steel compressor disk, the diameter of the forging piece is 960 mm, disk height is 210 mm, and the thickness of radial plates is 25 mm. In China, the compressor disks are die forged on a 12,000-ton hydraulic press. Abroad, the disk is die forged on a hydraulic press of more than 30,000 tons.

Figure 1 shows a thermal high-strength titanium alloy compressor disk; the diameter of its forging piece is 514 mm, the height of the wheel rim is 44 mm, and the thickness of the radial plates is 17 mm. This forging piece requires a pressure of 18,000 tons on a die forging hydraulic press. After improvement in technical design, a 40-ton·meter hammer-to-hammer-striking (without an anvil) machine can produce an identical disk forging, whose texture properties are good and production cost is drastically reduced.

Fig. 1. Thermal high-strength titanium alloy compressor disk (left) and its low-multiple texture (above).

In production of thermal high-strength titanium alloy compressor disk forgings, abroad the compressor disk forgings are mostly produced on large hydraulic presses. In China, after a series of technical tests conducted by aviation forging-press engineering circles, it was concluded that a titanium-alloy disk produced with high-speed forming equipment (hammer striking speed about 15 meters per second) has a compact texture, rational streamline distribution, and desirable comprehensive properties with considerably lower forging costs and energy consumption. These advantages cannot be obtained by using large hydraulic presses.

The high-speed forming technique can be used not only in forging of disk pieces, but also in batch production of compressor stainless-steel blades and titanium-alloy blades. China used high-speed hammers (6.5 to 75 ton·meter) to produce compressor blades and large fan blades; these blades were fitted in aircraft engines (see Fig. 2).

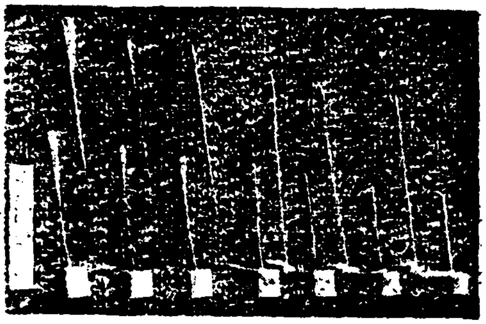

Fig. 2. Titanium-alloy (Ti-6Al-4V) compressor blades produced with high-speed hammer extrusion.

With a thermal die-forging mechanical press, we were successful in precision forging of Ti679 compressor blades used in the Spey engine. The blade forgings do not require machining; only polishing is sufficient. The shapes, dimensions, precision and allowances of blades meet the technical requirements of precision-forged blades. The texture properties are good (see Fig. 3).

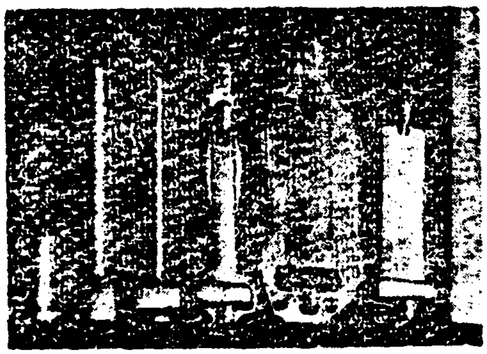

Fig. 3. Precision forging steps of high-pressure second-stage compressor blade used in Spey engine.

With a cold precision rolling technique, Cr17Ni2 stainless-steel blades can be produced; the blades are highly precise, require no excess amount (for machining) of forged piece, are higher than ∇8 in degree of surface finishing, and have good streamline directions. The service life of a rolling mold is five times that of an ordinary forging die; a set of rolling molds can roll 30,000 to 50,000 blades. The material utilization rate of the cold precision rolled blades can be raised from 11 percent (for ordinary die forging of blades) to 34~50 percent. Some aircraft engine plants built cold precision rolling blade production line; batch production of blades has begun.

The multi-directional die forging technique is another means of producing more precise forgings and improving the service properties. Multi-directional die forging is adapted to the production of complex-shaped forgings with internal cavities or convex rims. Through cooperation between the Beijing Aeronautical Material Institute and some aircraft plants, there were successful trial manufactures of fuel-oil pump casing of the Spey engine (see Fig. 4), missile nozzles, hydraulic booster cylinders, engine frame supports, and other complex die forged parts of various types.

Fig. 4. Fuel-oil pump casing of Spey engine.

Regarding production of medium- and small-size aluminum alloy forged parts, China's aircraft plants supplied more and more planar and volumetric precision forged parts; also developed were large aluminum forgings and refinement of blanks.

Technical Level of Aeronautical Castings

The advancement in development and level of production technique in aviation castings is manifested in a flow of modern casting alloys, ensuring metallurgical quality, and precision casting technique.

In high-temperature alloys used for casting, China has formed a series in production and applications. In China, there are more than 20 casting high-temperature alloys used for turbine blades and guiding blades during operation at temperatures of 750 to 1050°C. Some of the alloys achieve or surpass the level of the same type of alloys abroad in casting and comprehensive mechanical properties. At present, these alloys are smelted in equal-static-pressure crucibles of a vacuum induction furnace imported from West Germany's Leybold-Heraeus Company. The alloys are high in quality and pure in metal contents.

In the precision casting technique, alumina is used as the material for blade casing. As the resources of alumina (alumina composite, alumina chamotte, and Shangdian [transliteration] clay) are abundant and available at low cost, the consumption of electrically smelted corundum can be saved drastically. Alumina composite is a porous monetite--corundum refractory, which can be processed from China's abundant raw materials, rich alumina and high-quality clay; these constituents are blended according to the monetite formula and then blanks are prepared before calcining for long duration. Then, the blend is processed into grains, sorted by particle size, undergoes water dressing and is baked dry. The refractory is sold according to technical specifications; it has the advantages of high strength, little deformation, low linear expansion, and stable quality, and is adaptable for precision casting blades and directional crystalline blades without excess material for machining. Refer to Fig. 5.

In precision casting of hollow blades, ceramic cores are used (see Fig. 6); the castings thus produced can achieve the specified allowance, certain degree of finishing, wall thickness smaller than 1 mm, small holes of 0.2 to 0.5 mm in diameter, finishing degree of $\nabla 4$ to $\nabla 6$, and sufficient strength at high temperatures. For long and thin cores, no deformation or deviation will occur under gravity or impact by liquid steel. The core is not likely to break and

the wall thickness of castings is even. Moreover, a ceramic core has sufficient thermal stability and it is easy to separate the core from sand. As the trace elements, such as lead, zinc, iron and bismuth, are strictly controlled in the core, it has no reaction with metals.

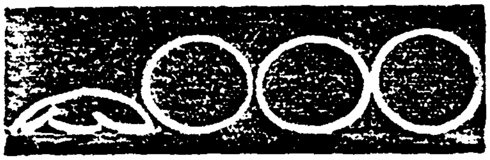

Fig. 5. Deformation photograph (1500°C, 0.5 hours) of ring specimens using various shell-shaped materials. Key: (1) Corundum; (2) Shangdian clay; (3) Alumina chamotte; (4) Alumina composite.

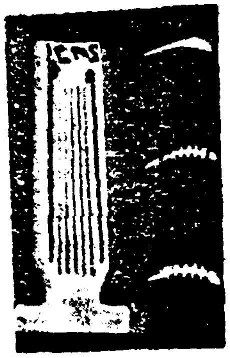

Fig. 6. Ceramic core (first-stage turbine blade).

The accuracy of precision casting blades is ±0.13 mm, the finishing degree is $\nabla 6$, and no machining is required for the blade surface. We have mastered the technique of precision casting of blades without any excess amount for machining; these technique steps include design of blanks, design and machining of dies, manufacture of paraffin molds (Chinese-developed paraffin molds have attained the British level of RR5), manufacture of the casing, smelting, pouring, measurement of dimensions, inspection of metallurgy quality, and precise positioning.

By adopting the directional crystalline furnace imported from the Leybold-Heraeus Company of West Germany and G.C.A. Company of the United States, directional hollow blades (see Fig. 7) of less than 200-250 mm in length can be poured by using the power reduction and quick condensation method. The included angle between columnar crystals can be controlled to less than 15°, and the number of columnar crystals at any cross section is not less than 5. In recent years, the directional blades have been undergoing platform test runs for long duration in engines of transport and fighter planes. As proved in experiments, the fatigue service life is 10 times higher, plasticity 4 times higher, and service life 2 times longer for directional blades than ordinary cast blades. The directional blades provide an effective, important measure in improving the performance of engines and prolonging service life of turbine blades.

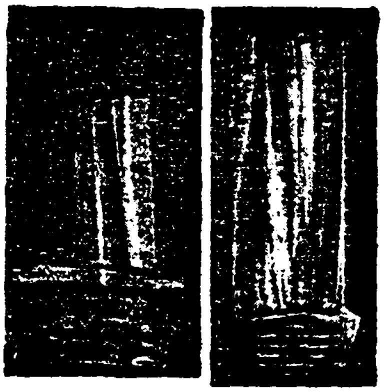

Fig. 7. First-stage turbine blades (directional blades) of an aircraft engine.

The casting titanium-alloy parts have extensive application prospects in aviation and civilian industries. The study and application of the titanium casting technique have been undertaken for nearly 20 years. In this period, there were adopted the graphite compaction model, graphite processing model, and graphite melting-die shell model to pour many types of aviation titanium castings, such as the engine compressor casing used in transport and fighter planes. After platform test runs, the compressor casings were proved to be effective. The maximum dimensions of castings may attain a diameter of 500 mm and length of

700 mm with maximum weight slightly less than 70 kg. The front support seats of the aircraft engine were certified by batch production and long-term utilization as meeting the design and operation requirements with a proven technique.

In order to assist researchers in medical divisions of orthopedics and artificial joints, artificial joints (such as knee joint and hip joint at base of thigh) were cast; these joints were tested by scores of patients. Their sufferings were gone and their normal work capabilities restored. The range of patients' ages was from 20 to 60.

With the industrial development, there have been ever expanding applications of casting steel, casting aluminum, and casting magnesium. At present in China, cold condensed resin sand forming has been extensively adopted to attain high accuracy and small deformation in castings. The forming technique is simple with low cost and saving of energy.

In order to reduce the structural weight of aviation parts to save raw materials and reduce machining time, in China the high-strength casting aluminum has been more and more used. The high-strength ZL-205 casting aluminum owes its high quality to the use of highly purified raw materials, blending of complicated alloyed elements, and heat treatment. Among the various versions of casting aluminum, at T_6 state, $\sigma_b \geqslant 50$ kg/mm^2 and $\delta \geqslant 3$ percent; at T_5 state, $\sigma_b \geqslant 45$ kg/mm^2 and $\delta_5 \geqslant 7$ percent. Eight different types of castings have been manufactured on a trial basis; under ordinary static testing, the aluminum castings can bear more than 150 percent of the rated destruction loading; this performance enables the aluminum castings to substitute aluminum forgings.

Productions of aluminum castings have been carried on for more than 20 years; the largest castings were 2-meter aircraft partitions and supports, as well as large engine shells more than 1 meter in diameter. By adoption of a sequential crystallization technique, large cylindrical magnesium parts can be cast with high production capacity and advanced quality control.

Conclusions

The products exhibited at China Aeronautical Forgings and Castings Trade Fair show a cross section of China's production of aeronautical forgings and castings.

In order to meet continuously improving properties of aviation products and to further raise technical and economic effects of forgings and castings, we are studying and developing the technique of preparing precision blanks. Some results have been attained in researches and tests of powder thermal equal-static-pressure and isothermal forgings, super-plastic forming, multi-directional die forgings, precision forgings and castings, and other precision blank preparation techniques.

ROUNDUP OF SCIENTIFIC RESEARCH ACHIEVEMENTS AT THE BEIJING AERONAUTICAL MATERIAL INSTITUTE

Luo Taiping

Recently, the Beijing Aeronautical Material Institute sponsored an exhibition of scientific research achievements. The exhibition items were divided into four major categories: metal materials, heat treatment technique, measurement and testing technique, as well as non-metal materials and their forming techniques.

Since the founding of the Beijing Institute, more than 750 items of scientific research have been successfully concluded: 115 items out of the 750 were given awards, including 84 items with important achievement awards bestowed by the State Council and ministries, and 31 items with important cooperation awards in scientific research achievements. At the exhibition, more than 240 items of scientific research achievements were displayed. Among these achievements, some have attained an advanced technical level in domestic and abroad and some others filled in China's technical blanks.

The major scientific research achievements in the exhibition are briefly introduced in the following.

Metal Materials

The displayed metal materials included deformation and casting high-temperature alloys, structural steels, deformation and casting titanium alloys, deformation and casting aluminum and magnesium alloys, and precious metal materials. Under the sharing efforts of the related domestic units, fundamentally these materials have formed a series. For example, among the nickel-base casting high-temperature alloys are K19, K19H and K002, and among the directional nickel-base casting high-temperature alloys are DK3, DK5 and DK22; their strengths at high temperatures and other properties have attained the levels of the same type of materials abroad. These alloys can be used in gas turbine blades operating at 950~1000°C, and guiding blades operating at 1000~1050°C. At present, the nickel-base casting high-temperature alloys used in turbine blades and guiding blades of aircraft engine have been generally used in China (see Fig. 1).

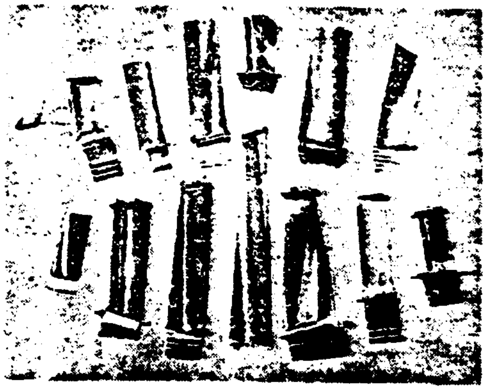

Fig. 1. Some turbine blades made of K-series nickel-base casting high-temperature alloys.

Successfully developed in China, the GH140 is an iron-nickel base high-temperature alloy used as a plate material. The base of the alloy is Fe-37Ni-20Cr solid solution, and then it is compound strengthened on austenite with alloy elements, such as W, Mo, Al and Ti. These alloy components can maintain single-phase austenite texture after treating alloys with solid solution. The GH140 alloy has good resistance to oxidation, high plasticity, and adequate properties in thermal strength, thermal fatigue, punching, and welding. The GH140 alloy can substitute for GH30 and GH39 nickel-base high-temperature alloys to make components in combustion chamber and booster combustion chamber of aircraft engines and power-generation gas turbines (see Fig. 2). This alloy (plate

material) is reliable in performance, and capable of saving large quantities of metallic nickel for the state, therefore the production of GH140 alloy is the highest (of high-temperature alloys) in China.

The GC-4 nickel-free superhigh strength steel is a key material in making aircraft's important structural members under stress. The tensile strength σ_b of GC-4 is 180 to 200 kg/mm^2. The torsional (and shearing) strength and stress, and anti-corrosion properties are higher than that of $30CrMnSiNi_2A$ steel. However, the notch sensitivity and anti-fatigue properties (under repeated loadings) of GC-4 are less than desirable. By using different standards of isothermal treatment, GC-4 steel can attain different mechanical properties in order to meet design and operation requirements. The steel can be used to manufacture landing gears, joints, bolts and other parts under stress in an aircraft.

Through cooperation by the Beijing Institute and other related units, there were successfully developed F26, SFCu-1, F7501, 502, 703 and 245 metal-ceramic brake materials; these materials have formed a series with good friction properties. The 703 is superior in braking efficiency (by more than 100 percent) in laboratory conditions than the brake materials used in Boeing 707 aircraft. The technical properties of the 245 brake material attain or surpass the level of similar material abroad as the service life of 245 in an An-24 aircraft is more than twice as long as the FMK-11 material of the USSR. At present, these materials have been extensively used in various models of aircraft. The Chinese-made brake materials used in new and old models of aircraft are popular in domestic market. The brake materials used in imported civil aircraft also have been gradually replaced with Chinese products (see Fig. 3), thus saving considerable foreign exchange every year.

The successful development of materials for gold-base electric contact elements used in aviation instruments and meters has improved China's passive situation of solely relying on imported platinum and palladium-base alloys. The gold-base electric contact materials have additions of silver, chromium, manganese, nickel, and molybdenum alloy elements to gold, forming a gold-base alloy series, whose electrical, mechanical and physical properties are the same as the platinum- and palladium-base alloys. The gold-base electric-contact-element materials have good stability while contacting with chemicals and also provide high resistance against organic-gas contamination. In the environment-gas corrosion conditions

(such as in the oxidized, sulfurized and sea-fog areas), the variation of electric-contact resistance in the case of gold-base materials is small, so it can substitute platinum- and palladium-base alloys to be used as materials for winding, electric brush, sliding contact, conducting ring, and conducting sheet. The adoption of gold-base materials can improve the quality of instruments and meters and reduce importation of rare or much demanded materials; thus, the gold-base electric-contact materials are generally used domestically.

Heat Treatment Techniques

In heat-treatment techniques, the directional condensation technique for making high-temperature alloy turbine blades attracted the most attention. This new technique was successfully developed by the Beijing Aeronautical Material Institute with close cooperation of other related domestic units. The use of quick condensation technique can obtain columnar crystal castings with [001] selective direction (parallel to the main axis of parts) properties. The length of the columnar crystal may reach 200 mm. The quality and technical parameters of the directional condensation castings have basically attained or approached the level of foreign countries. The successful development of directional condensation technique means that China's precision casting technique of turbine blades has reached a new level. This development solves a key technical problem in developing high-performance aircraft engines.

In 1980, the development of modern casting non-poisonous magnesium sand was presented with the third-class invention award by the State Council; this creative development was the cooperative result of the Beijing Institute and other related units. The casting non-poisonous magnesium sand can substitute for poisonous sand (containing a fluorine additive) for magnesium castings. For a long time, China used molding sand containing a fluorine additive; during pouring several poisonous gases (such as HF, SiF_4 and NH_3) are released to contaminate the environment, to corrode plant equipment, and most importantly to seriously impair workers' health. Various types of magnesium alloy castings can be produced by pouring into modern magnesium-casting non-poisonous sand molds; these castings were accepted with quality evaluation. These sand molds are simple to prepare and low in price, thus relieving fluorine's damage to human body.

The HLCu-1 and HLCu-2a copper rods are used to manufacture aviation stainless-steel guide tubes; these copper rods were developed according to application conditions in China. The Chinese copper rods are up to the same level of technique and mechanical properties as that of PZhL-500 rods in the USSR, but the welding temperature (of the Chinese rods) is lowered by 80 to 100°C compared with PZhL-500. Therefore, the Chinese copper rods are free from defects of growing alloy-base crystals, surface melting or erosion, and too deep infiltration into intercrystal spaces.

The technique of pill-spraying strengthening is extensively used not only in the aviation (parts) industry but also in other machinery industries. The strengthening of pill spraying can improve the fatigue strength of parts and also prolong the service life. The Beijing Institute is exploring new ground in the fundamental research on regimes in strengthening pill-spraying.

Fig. 2. High-temperature parts made of GH140 alloy.

Fig. 3. Chinese-made modern friction-material brake disks.

Successfully developed were thin aluminum plastic films and a nitrogen-filled sealing technique; these new developments attain an advanced domestic level, by reducing quantities of out-of-date products with less repair and scrapping as well as providing convenient conditions for strategic reserve and rotational production.

Good achievements were attained in studies of explosion spraying-coating equipment and technique. China's first explosion spraying and coating equipment was successfully built; in addition, the technique was studied of explosion coating-spraying of Ni-Cr-B-Si, Al wrapped in Ni, and WC wrapped in Co (five coating layers).

Measurement and Testing Techniques

The scientific research results of measurement and testing techniques include measurement testing of mechanical properties, analysis of metal materials, metal physics, and no-loss testing; more than 60 items using the techniques were displayed. In measurement and testing of mechanical properties, the Beijing Institute has more than 200 sets of testing equipment in various types, capable of conducting mechanical property tests and studies for different materials. In studies of material breaking due to fatigue, the institute has advanced facilities with significant achievements in design and material selection for new machines, in analysis of major breakdowns, and lengthening service life of products. Ten items of research achievements in fatigue breaking were awarded and commended by the State Council and the Third Ministry of Machine Building. Among the 10 items, the fatigue (S-N) curve commonly used in aviation metal materials is the first major scientific-research achievement through the cooperation of 18 domestic units organized by the Beijing Aeronautical Material Institute and the Beijing Aeronautical Engineering College. Altogether, 96 S-N curves and 28 equal-life-span curves were derived for 12 common aviation metal materials under various conditions. These curves provide references in aircraft design, and in prolonging and determination of service life.

The electron diffraction analysis is a physical means of studying the texture and structure of important metals. Based on many years' work activities, the Beijing Institute established a number of matrix analysis methods for the electron diffraction spectrum. Comparing their methods with similar ones, both domestic and abroad, the Beijing Institute's methods have exclusive characteristics. For example, in the direction-selecting relationship between two phases, the Chinese method improved Wujiefusike's [transliteration] work of the USSR to independently derive the transformation matrix formula of the direction-selecting relationship and to discuss systematically methods of handling such a problem. A successful matrix method was proposed to handle the direction-selecting relationship of other than 180° rotational twinning crystals. According to this set of matrix methods, an [electronic computer] program was written in marking complicated electronic diffraction spectra of two phases, twinning crystals and high-level Lloyd belt. As proved in practice, this method is accurate, reliable, and easy to learn with time economy. Moreover, this method helps to promote automation in electron microscope research.

The fluorescence infiltration method is one of the important no-loss measurement and testing methods in the aviation and machinery industries. A new fluorescence infiltration liquid was presented with the third-class invention award by the State Council in 1979; the liquid was developed through the cooperation of the Beijing Institute, the Shanghai Research Institute of Organic Chemistry (of the Chinese Academy of Sciences), and the Hongan Machinery Corporation. This fluorescence infiltration liquid is composed of high-boiling-point solvents, surface activating agents, infiltration agents, coupling agents, preservatives, and fluorescence dyes. Since refined petroleum distillates are adopted in constituents of the fluorescence infiltration liquid, the other constituents (sulfur, sodium and halogen elements) are reduced. Thus, the flash point of the fluorescence liquid is raised to a temperature higher than 80°C, thus satisfying requirements of quality testing of aviation products. This fluorescence liquid can be used to detect defects of many manufactured products; its fluorescence intensity, infiltration, cleaning property, and sensitivity are up to the level of similar products abroad.

Non-metal Materials and Forming Techniques

Of non-metal materials, there were more than 60 items exhibited, including plastics, rubber, adhesive agents, sealing materials, fuels, lubricants, special liquids, coating agents, and heat insulation materials. Aircraft cabins and integrated fuel tanks are sealed with room-temperature sulfide sealing agent, sealing colloid film, and non-sulfide sealing putty; these three sealing substances have basically formed a series. The major properties of some sealing materials are comparable with those of similar materials abroad.

Under development are microwave absorption materials, which have properties of low reflection, high separation attenuation, softness, and light weight in addition to an advantage that no metal reflection lining is required. Once such materials are developed, radar tactical properties can be improved.

A rubber electron-microscope hardness meter was developed through cooperation of domestic units. By utilizing a new technique of differential transformations and the advanced electron technique, the denting depth can be converted into electric signals, shown by a digital voltmeter. This hardness meter can not only

automatically increase loading, but also raise reading precision and sensitivity. In addition, the meter is good in stability and repetition of data.

Radar casings (see Fig. 4) were formed with a pressured pouring technique, which is the first such achievement in China. Passed in statistical testing, ground electric-characteristics testing, and test flying, the radar casing rigidity and strength meet design requirements.

In the 25 years, the Beijing Aeronautical Material Institute attained good achievements in scientific research; the institute trained a number of scientific-research cadres of a certain technical level in making due contributions to China's aviation industry.

Fig. 4. Radar casing formed with pouring technique under pressure.

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